The Influence of El Niño Phenomenon on the Climate of Venezuela

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Abstract. Annual rainfall distribution in tropical America depends on the ITC zone, affected by factors such as Andes Mountain, tropical Pacific and Atlantic Oceans and local convergence areas. Studies have showed correlation between the ENSO Phases and hydrologic anomalies in the region. In Venezuela ENSO effects are reflected as climatic anomalies with magnitudes varying within the areas. This paper deals with the study of the effects of El Niño phenomena on the climatic variables in Venezuela. Variables affected directly by El Niño are rainfall, temperature and flows. Indirectly consequences are associated with an increase of diseases such Malaria, Dengue and Cholera. ENSO phenomena create anomalies in Hadley cells over Venezuela originating negative anomalies for rainfall during El Niño years and positive rainfall anomalies during La Niña events. Results of correlations between this anomalies and SSTA-3/4 have show negative rainfall anomalies between 8 and 20 % and positive anomalies of 14 to 30 %, depending on the region. About 85 % of ENSO years coincide with rainfall deficits bigger than 35 %. Temperature values are less sensitive to the occurrence of El Niño, varying the magnitude of the anomalies between 0.5 ^{0}C to 1 ^{0}C, high enough to increase the transmission of Dengue in a rate of 100 %. Malaria mortality and mobility increases in 37 % the year after an El Niño event. The relationship between ENSO 3/4 Indices and flow anomalies of Caroní River shows that the join occurrence of atmospheric and oceanic events exercise the biggest influence on the occurrence of flow anomalies in this basin. During the cold El Niño period in the Pacific (La Niña) flows in Caroni basin diminish affecting the storage and level of operation of Guri reservoir and the production of hydro electrical energy. In fact, 12 from the 15 El Niño events that happened during the analyzed period of flows (1950-2004) coincide with years in which mean annual flow is far smaller than the historical mean.
Keywords: Climatic anomalies; ENSO in Venezuela; effect of El Niño in Venezuela; influence of ENSO on the Climate of Venezuela; effects of tele-connections.

1. Introduction

The global connection *El Niño-Southern Oscillation* (ENSO) originate climatic anomalies in other places of the world. In the case of Venezuela the results are the cold winters that affect the hydro electrical energy production, the agriculture, and increment the tropical deceases. Climatologists have already developed promising models to forecasting the onset of ENSO episodes (Guevara, 2002). For Venezuela it is necessary to establish the relationship between ENSO episodes und the effects that they cause in the national economy. The influence of ENSO events on Venezuela are manifested through the variation of rainfall and temperature anomalies, which magnitude varies according to the region affecting clime, agricultural production, health and hydroelectric energy generation.

The annual rainfall distribution in Venezuela is mainly determined by the position of the Inter Tropical Convergence (ITC) zone. Other factors are Los Andes Mountains, the Caribbean mountains and Maracaibo lake.
In this paper will be presented the results of the quantitative analysis of influence on ENSO on rainfall and temperature anomalies and the qualitative analysis on the tropical diseases. Bein the Caroni basin the source of 64 % of the energy consumed by the whole country, it is necessary to investigate the relationship between the onset of ENSO episodes and their effect over the flows of Caroní River. In this paper will be also be presented the relationship between ENSO Indices and the flow anomalies of Caroní River, using the time series of monthly mean flows observed at Guri Gauging Station during the period of 1950-2003.

2. The development of an ENSO episode

"El Niño" (EN) refers to the occurrence of abnormally high sea–surface temperature (SST) off the coast of Peru;"Souther Oscillation" (SO) refers to the accompanying low atmospheric pressure over the eastern Pacific and the high atmospheric pressure in the western Pacific. ENSO is a combine quasi-cyclic phenomenon that occurs every three to seven years, lasting 12-18 months and resulting usually in warm or cold winters in particular regions, drought in normally productive agricultural areas, and torrential rains in normally arid regions; it begins in a September, when the westward trade winds in the western equatorial Pacific are abnormally strong and SSTs in the eastern equatorial Pacific are low. In December, an anomalous eastward wind flow develops near the International Date Line, and the eastern SSTs begin to rise. Accompanying this eastward airflow, the extensive pool of high-SST water that usually exists in the far western equatorial Pacific begins to move eastward. This movement causes the sea level in the western Pacific to drop, while that along the Peruvian coast rises as much as 10 cm by April. December and January usually mark the "mature" stage of development of an ENSO episode, when low pressures exist above the widespread warm water in the eastern Pacific and the westward (easterly) equatorial winds essentially cease. Following this, SSTs in the easternmost Pacific begin to decline rapidly and are usually at below-normal levels by May. The end of an ENSO episode begins when the eastward waves of warm water are reflected off South America and, in a complicated process that involves pole ward circulation of the reflected westward-moving surface water and atmospheric processes, the SST returns to its original levels and the easterly trade-winds flow is reestablished.

ENSO involves major dislocations of the jet steams that can steer unusual weather systems into low- and mid-latitude regions around the world. The Southern Oscillation Index (SOI), defined as the normalized difference in surface pressure between Tahiti, French Polynesia and Darwin, Australia is a measure of the strength of the trade winds, which have a component of flow from regions of high to low pressure. High SOI (large pressure difference) is associated with stronger than normal trade winds and La Niña conditions, and low SOI (smaller pressure difference) is associated with weaker than normal trade winds and El Niño conditions.

El Niño has also become synonymous with larger scale, climatically significant, warm events. There is not, however, unanimity in the use of the term El Niño. The tendency in the scientific community though is to refer interchangeably to El Niño, ENSO warm event, or the warm phase of ENSO as those times of warm eastern and central equatorial Pacific SST anomalies. Conversely, the terms La Niña, ENSO cold event, or cold phase of ENSO are used interchangeably to describe those times of cold eastern and central equatorial Pacific SST anomalies. The terms A-ENSO (Anti-El Niño) has also been applied to the cold phase of ENSO. NOAA (2004a) has developed operational definitions for El Niño and La Niña. The index is defined as three-month averages of SST departures from normal for a critical region of the equatorial Pacific (Niño 3.4 region; 120W-170W, 5N-5S). According to this definition, **El Niño/La Niña** is a phenomenon in the equatorial Pacific Ocean characterized by a **Positive/Negative** SST departure from normal (for the 1971-2000 base period) in the El Niño 3.4 region greather than or equal in magnitude to 0.5^{o}C, averaged over three consecutive months.

3. Metodology

A total of 12 indices were established to be correlated with rainfall ant temperature anomalies of the whole country and the flow anomalies at Guri Gauging Station of Caroní basin in the southern region of Venezuela(Cardenas et al., 2002; Marín y Guevara, 2004; Guevara, 2005; NOA, 2004b; JISAO, 2004):

El Niño1/2 0 - 10° S; 90 - 80° W
El Niño 3 5° N - 5° S; 150^{o} - 190° W
El Niño 4 5° N - 5° S; 160° E - 150° W
El Niño 3/4 5° N - 5° S; 170 - 120° W
ENSO1/2 = |MASOI| * MAEl Niño1/2 * 100
ENSO 3 = |MASOI| * MAEl Niño 3 * 100
ENSO 4 = |MASOI| * MAEl Niño 4 * 100
ENSO 3/4 = |MASOI| * MAEl Niño 3/4 * 100
NATL (North Atlantic) 5 - 20° N; 60 - 30° W
SATL (South Atlantic) 0 - 20° S; 30° W - 10° E
TROP (Tropical Belt) 10° N - 10° S; 0 - 360^{o}
QBO-Index

MA means the moving average of the three months of SOI and SST in the corresponding El Niño region.

Following ranges were taken for the Intensities:
El Niño Wke (W) when: 0.65^{o}C < SST-Anomaly < 1.0^{o}C
El Niño Moderate (M) when: 1.0^{o}C < SST-Anomaly < 1.5^{o}C
El Niño Strong (S) when: SST-Anomaly > 1.5^{o}C
ENSO 3/4 Wake wake (W)when: 40 < ENSO 3/4 < 85
ENSO 3/4 Moderate (M)when: 85 < ENSO 3/4 < 216
ENSO 3/4 Strong (S)when: ENSO 3/4 >216

The effect of seasonality of monthly flows was eliminated dividing each flow anomaly ($Q_{ij} – Q_m$) by the mean flow of the corresponding month, Q_m, as folowes:

$QA_{ij} = 100 \times (Q_{ij} - Q_m)/Q_m$

where QA_{ij} are the flow anomalies for year i and month j to be correlated with the above described indices; Q_{ij} are the flow events for year i and month j; and Q_m is the corresponding mean monthly flow.

4. Results

4.1 ENSO and Rainfall

General speaking the occurrence of rainfall excesses due AENSO events are more frequent than rainfall deficits due to ENSO events. The best correlations were those with one month lag for AENSO events and for the region of Guyana (southern part of Venezuela were Caroní basin is located). Table 1 shows the Percentage of monthly rainfall anomalies for all events associated with AENOS and ENOS divided in three groups: S = strong; M = Moderate; all events together. The table indicate that the anomalies are positive for AENSO and negative for ENSO events. Positive anomalies have bigger absolute values.

Table 1. Percentage of monthly rainfall anomalies for all events associated with AENOS and ENOS (S = strong; M = Moderate; all). Fuente: Cárdenas (2002b)

REGIONS	ENSO Events			A-ENSO Events		
	F	M	All events	F	M	All events
Guyana	-16.03	-14.36	-13.15	20.43	18.53	18.75
Delta plains	-21.60	-18.19	-16.91	28.41	22.88	20.23
Los Llanos	-11.94	-12.88	-10.44	19.70	20.48	18.05
Los Andes Mountains	-25.48	-24.12	-20.22	45.89	36.20	29.26
Coro Mountains	-19.40	-20.20	-15.02	39.10	33.70	31.00
Maracaibo Lake Depresión	-15.06	-14.55	-9.03	31.08	21.64	14.73
Coast Mountains and Islands	-15.59	-16.09	-8.64	15.58	21.19	14.04

Figure 1 shows the magnitude of rainfall anomalies for regions and type of event. Positive anomalies are bigger for Los Andes regions. Negative anomalies are smaller for Guyana region.

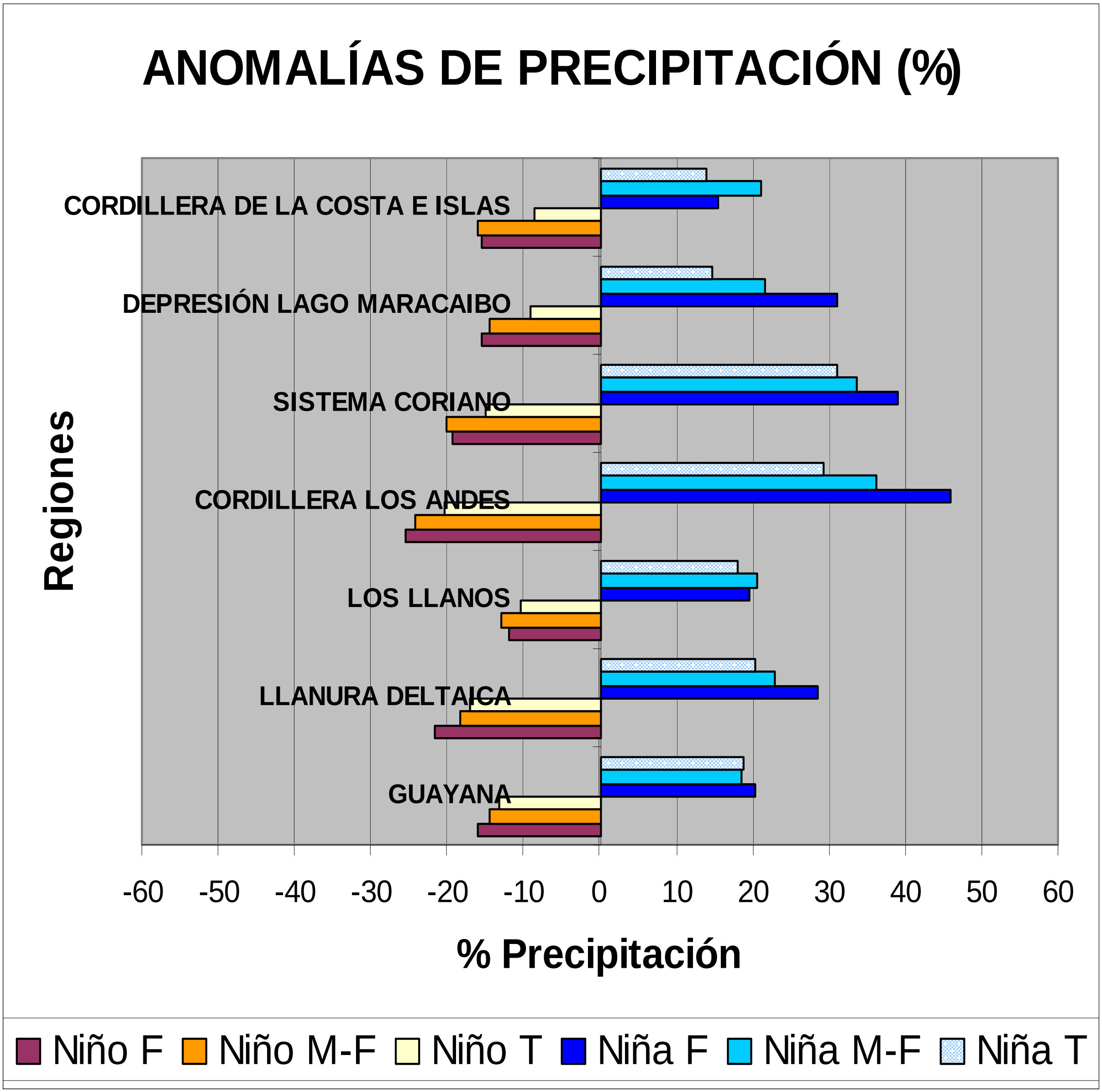

Figure 1. Graphical representation of rainfall anomalies for regions.

4.2 ENSO and Temperature

Temperature anomalies are almost always positive. There are regions with mean anomalies bigger than 0.5 ºC almost for all months of the year. The general tendency is that ENSO events increment the mean temperature all over the country, being the bigger positive temperature anomalies during the dry period: November to April. It is worth to mention that during ENSO 1997-1998 occurred negative anomalies en some regions of Venezuela but the positive anomalies were a high as 2.0 ºC in other regions.

4.3 ENSO and Health

Malaria: Malaria mortality and morbidity increases in following ENSO year around 37%.

Dengue: It has been found that the increase of one degree centigrade in the temperature can increase twice the transmission of Dengue. AENSO events originate positive rainfall anomalies from 14 to 36 % increasing the survival of mosquitoes

Cholera: Cholera normally outraces in extreme clima conditions (droughts or floods). But during the ENSO 1997 the origin was socioeconomic . Infections came from sea products and very bad sanitary conditions of water supply and sewerage

4.4. Effect of ENSO on flows of Caroní river and the hydro electrical production in Venezuela

The Caroní basin is located in the South-East of Venezuela (See Figure 2) between 3^o 40`and 8^o 40´N and 60^o 50´and 64^o 10´W; it has an area of 96.000 km^2 (10% of the country). Caroní River extends from Brazil-border to the confluence with the Orinoco River near the city of Puerto Ordaz. Orinoco River pours the waters into the Atlantic Ocean. Caroní basin is divided in two sections: the Upper Caroní Basin formed by the so called “Great Sabana” and the Lower Caroní basin until its outlet in the Orinoco River The mean annual values of the meteorological parameters over the basin are: precipitation 2.800 mm; temperature 27^oC; evaporation 2.000 mm; relative humidity 76 %.

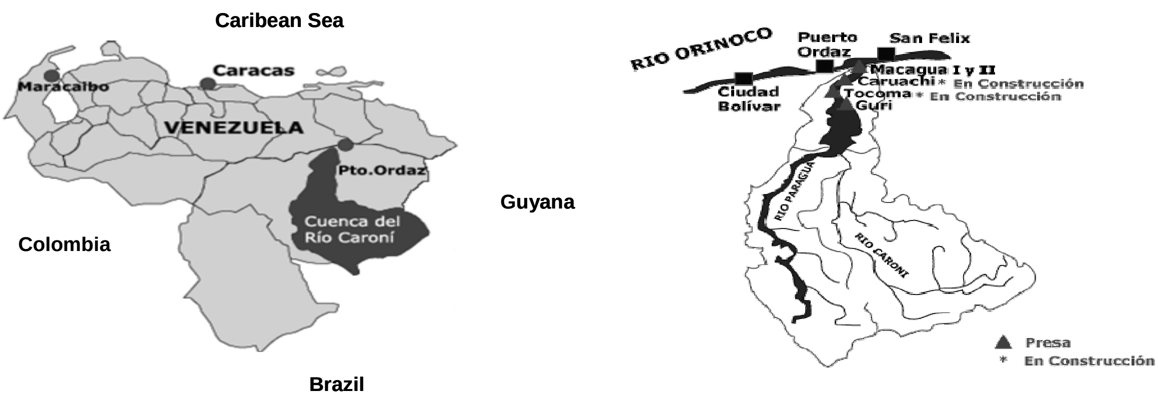

Figure 2. Location of Caroní basin.
Source: EDELCA 2004

Figure 3 shows the monthly mean river flows averaged over the period 1950-2003, which displays a well-defined annual cycle with the maximum during the summer (9.159 m^3/s in July) and the minimum in winter (1.404 m^3/s in March). The mean anual flow for the period is 4.835 m^3/s with a standard deviation of 711 m^3/s and a coefficient of variation of 0.147. (Guevara, 2005).

From the total installed power capacity of the country (19.000 MW), 60 % is hydro electrical. Caroní basin represents around 90% of this hydro power and 64 % of the total annual energy production of the country (91.000 GWh/year) (EDELCA System). The energy is generated mainly by Guri Plant (Guri Reservoir) which was built on the Caroní River bed 100 Km upstream from its junction with Orinoco River. The reservoir has a total capacity of about 100 thousand million cubic meter (the eighth. biggest of the world), a water surface of 4.5 thousand square kilometer, and a normal operation level at height of 272 masl (EDELCA, 2004; Marín and Guevara, 2004). EDELCA System is operated by EDELCA (Electrificación Del CaronÍ) and is interconnected with the Electrical National System (SIN).

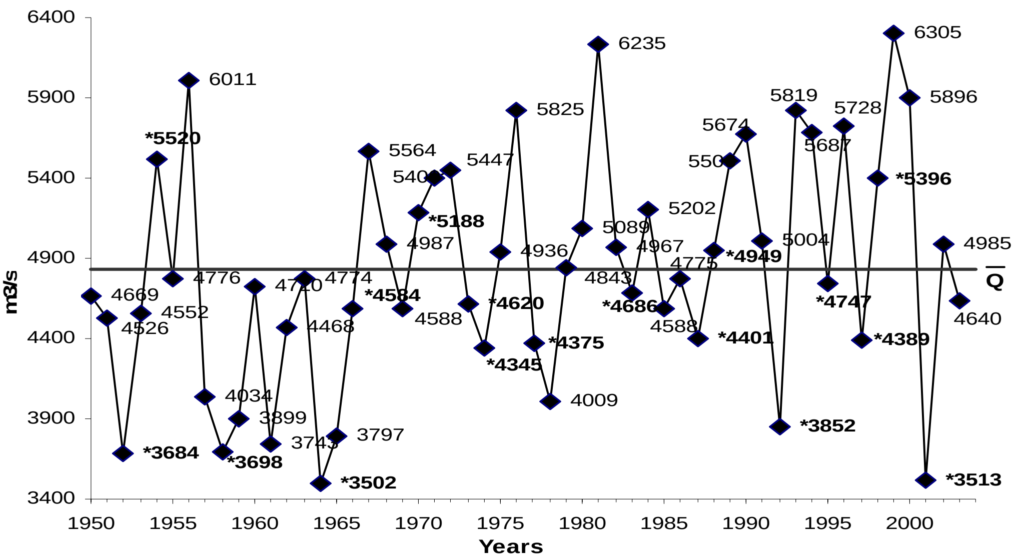

Figure 3. Historical flows of Caroní river at Guri Gauging Station. Red numbers are coincident with El Niño event years.

Guri reservoir shows a hydrologic multi annual regulation of three years. For this reason the ENSO phenomena does not affect direct the energy production of EDELCA System but this effect is notorious in the drawdown of the operation water level of the reservoir which in turn forces to turbinated bigger volumes of water to keep the balance in the energy generation of the national system. Nevertheless this effect can be alleviated by a join operation of Guri and the other hydro plants locates downstream (Macagua I and II). The ENSO event of 92/93 affected the flows of Caroni River and as a consequence, Guri reservoir drawdown level to its historical minimum (CAF, 2000). The 97/98 ENSO also caused a decrease in the flows of Caroni River, and obligated to EDELCA and SIN to consider an increase of vapor energy production as a preventive measure to confront the energy crisis during the period of March-May 98. Even if the effects of this energy crisis was not noted by the energy users, indeed the volume of Guri reservoir descend during this period in about 16 thousand millions of cubic meter (20 % of its capacity) equivalent to 7 thousand GWh/year (only 12 % of the total energy generation). To cover the difference the termic plants used 7.8 % more gas (226 millions of cubic meter) and 31.7 % more fuel-oil (511.000 MT) during the same period.

The onset of the raining season was delayed in comparison with normal years in 1997; temperatures and evaporation, as well as the dry season intensified from November to April. In January 1998 the rainfall anomaly (deficit) increased to 20 % compared with normal years. Maximun and minimum values of temperature increased between 1 and 4^{o} C. Compared with historical data, the flows of Caroní river showed a normal behavior from January to June 1997; after July of the same year, flow anomalies increased but negatively (flows decrease) until January 1998 reaching values near the historical minimum.

The flows in Venezuelan rivers rich the highest values at the end of the summer of La Niña years and the lowest values during the winter of El Niño years (Caviedes, 1997; Caviedes y Waylen, 1997). Caroní River is not the exception. Figure 2 shows the historical flow of Caroní River in Guri Gauging Station for the period 1950-2003. From the 14 El Niño years that happened in the period 1950-2003, 12 correspond to years with flow values in Caroní River smaller than the historical mean (CONICIT, 1998; Guevara, 2005), where the flow discharge is smaller than the historical mean (numbers with asterisk in Figure 2 correspond to ENSO event years).

5. Results of the Correlations

The results obtained by the correlation between Flow Anomalies of Caroni river at Guri Gauging Station and the 12 Indices as described above are presented in Table 1. The best correlation is showed by the Index ENSO 3/4. This index is a composite one that includes the moving average of the last three months of both, the SOI Index, and the SST Index in the region El Niño3/4. The fact that the best correlations are obtained with the use of composite indices (ENSO) means that the join occurrence of atmospheric and oceanic events (tele-connections) exercise the biggest influence in the occurrence of flow anomalies in the Caroní river (Cardenas, 2000, 2002; Marín and Guevara, 2004).

To evaluate the influence of ENSO on the flows of Caroní river a variance analysis was applied to the flow anomalies dividing the historical data according to the percentile distribution of the indices capable to define the phenomena in samples corresponding to ENSO event years. The groups or cases were established as follows:

ENSO conditions are given when : ENSO 3/4 > 80 percentile
Normal conditions are given when: 20 percentile < ENSO 3/4 < 80 percentile
Anti-ENSO (A-ENSO) conditions are given when: ENSO < 20 percentile

The results of variance analysis are given in Figure 3, where bigger (and positive) values belong to A-ENSO events, being the highest for the dry period of the year. For ENSO events the tendency is similar but the values are negative and smaller that for A-ENSO. This results clearly show the effect of tele-connections on the flow anomalies of Caroní River.

Analogous criteria have been used by Cardenas y Waylen (2002) to define the occurrence of El Niño cases based on the percentile distribution of El Niño3/4 and the occurrence of SO events, this last one, from the percentile distribution of SOI Indices.

An additional analysis was done considering the strong ness of the phenomena. The result is given in Figure 4, which shows an improvement of the significance levels as the intensity of the meteorological event increases for all analyzed cases. Here the A-ENOS is responsible for the highest positive flow anomalies, especially during the dry period of the year.. In other words, there is a direct relationship between the intensity of the phenomena and the magnitude of the flow anomalies.

When analyzing the effects of ENSO over the flows of Caroní River it is advisable to consider also the incidence of the QBO Indices. At this respect trials were done with the cases showed in Figure 5. The results given in the Figure indicate that the Indices QBO modulate the effects of ENSO over the flows of Caroni river quite good. Qualitatively speaking, for low east and west velocities of QBO Index, the effect of ENSO over the flows increases in some degree. High east velocities of QBO, result in higher positive flow anomalies than those corresponding to west velocities (Cárdenas, 2000)

The modulation of flow anomalies by the QBO Indices for the case A-ENSO results in a direct relationship between QBO and Anomaly values but all of them are positive. For the case of ENSO, which general mean value of the modulated anomaly is negative, the results do not show a definite tendency and the values can be either, positive or negative. This means that there is a direct influence of La Niña (cold phase of El Niño) over the flow anomalies of Caroní river.

The conclusion is that during the cold El Niño period in the Pacific (La Niña) the flows in Caroni river diminish affecting the storage and the level of operation of the reservoir and the production of hydro electrical energy. Knowledge of this fact can help authorities to make better decisions on the operation of the National Interconnected Electrical System (SIN) when an episode La Niña (A-ENSO) is foreseen.

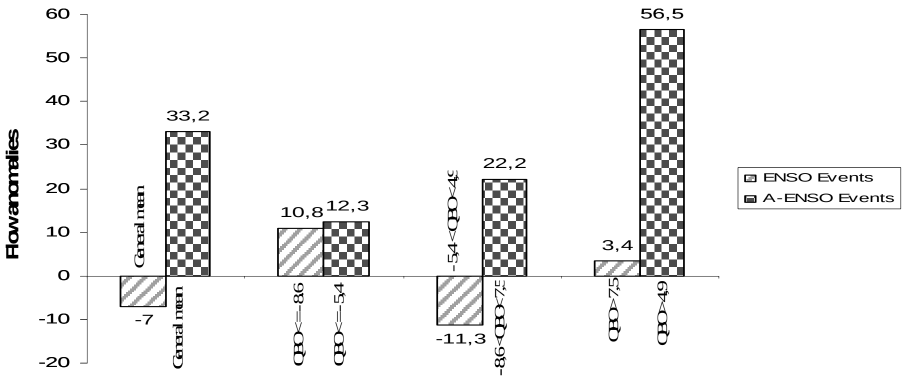

Figure 4. Results of the variance analysis in % for the flow anomalies of Caroní river using the Indices ENSO 3/4 (best correlation) for ENSO and A-ENSO (La Niña) events.

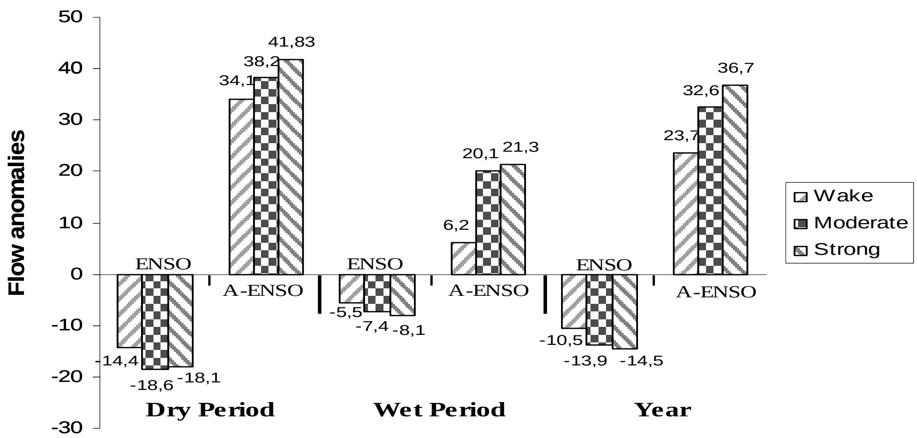

Figure 5. Effects of ENSO and A-ENSO events normalized (modulated) by the QBO-Indices on the flow anomalies of Caroní river at Guri Gauging Station.

Table 1. Correlation coefficients obtained between the 12 established indices and the monthly flow anomalies (QA) of Caroni river at Gurí Gauging Station for the period 1950-2003.

Event	Índice	Correalation with QA
ENSO	ENSO 1/2	-0.152**
	ENSO 3	-0.216**
	ENSO 3/4	-0.260**
	ENSO 4	-0.251**
Southern Oscillation	SOI	0.217**
El Niño	El Niño1/2	-0.031
	El Niño 3	-0.122*
	El Niño 4	-0.158**
	El Niño 3/4	-0.192**
Others	NATL	-0.060
	SATL	-0.103*
	TROP	-0.1957**

Note: (**) significant correlations with $\alpha = 0.001$ (*)s

6. Conclusions

The warming process of the equatorial Pacific water surface temperature (El Niño), as well as the ENSO phenomenon, called here El Niño 3/4 Index, cause important anomalies in the climatic parameters in Venezuela, such as in the regimen of rainfalls, temperatures and flows. The influence of the phenomenon shows up as negativ anomalies (defficit) of rainfall and flow during the El Niño, and positive anomalies (excess) of rainfall and flow during La Niña episodes, being the positive anomalies bigger than the negative ones.

The flows of Caroní River are directly inffluenced by the ENSO episodes. This effect shows up as a decrease of the flows during the winter period of North Hemisphere. In addition of ENSO, there are at least two other indices that modify or modulate the flow anomalies in Caroní river: the QBO (Quasi Biennal Oscilation) and the DPO (Decade Pacific Oscilation).

The ENSO 3/4 Idex is the one that shows the highest correlation with the flow anomalies of Caroní River in Guri Gauging Station. The flow anomalies are negative for ENSO events and posituive for A-ENSO episodes. The values of the anomalies increase as the strength of the ENSO event increase.

For low east and west velocities of QBO Index, the effect of ENSO over the flows increases in some degree. High east velocities of QBO, result in higher positive flow anomalies than those corresponding to west velocities.

There is a strong coincidence between the occurrence of ENSO events and the occurrence of droughs in the Southern Region of Venezuela.

This affects the hidroenergy production since Caroní basin generatates more than the 60 % of the energy consumed by the whole country.

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